SOME LOCAL EFFECTS OF THE SAN FRANCISCO EARTHQUAKE

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The principal damage done by the San Francisco earthquake of April 18, 1906, was confined to a long, narrow area extending along the Pacific coast in a northwest-and-southeast direction, with the city of San Francisco near its center. The area in which the greatest damage was done is a little over 200 miles in length and scarcely 40 miles in width. The earthquake may be accounted for by the geological structure. The principal valleys of California have been formed by a system of parallel faults running in a general northwest-and-southeast direction, and the disturbance occurred along one of these old fault-lines.

The particular fault which caused the earthquake is the Stevens Creek fault; it has been traced across the Santa Cruz quadrangle by Dr. J. C. Branner and Dr. J. F. Newsom, and is described by them in the unpublished Santa Cruz folio of the United States Geological Survey. It runs from Crystal Springs Lake through Woodside and the Portola Valley, over the saddle that joins Black Mountain with the crest of the Santa Cruz Range, down the Stevens Creek canyon, crosses Campbell Creek about 2 miles southwest of Saratoga and continues in the same southeasterly direction toward Loma Prieta. From Crystal Springs Lake the fault has been traced toward the northwest by Professor A. C. Lawson through San Andreas Lake and out into the ocean near Mussel Rock, about 7 miles south of the Cliff House at San Francisco.

The topography appears to indicate that the fault-line continues its northwesterly course through Bolinas Bay and Tomales Bay, and that it finally leaves the coast near Point Arena in Mendocino County.

The present paper deals only with the movements that took place along this fault-line between Crystal Springs Lake and Black Moun-

tain, and with the effects of the earthquake on the district lying on both sides of the fault-line and extending from San Francisco Bay to the Pacific Ocean.

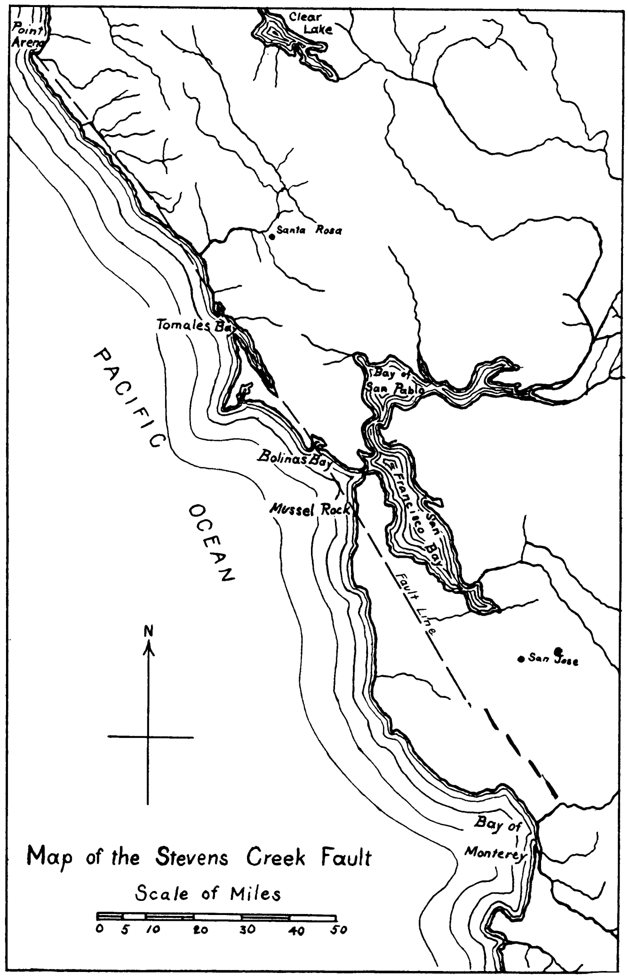


FIG. 1.

The Stevens Creek fault is one of the most recent, fcr it cuts gravel beds that were laid down as late as the Pliocene or perhaps Pleistocene period. The old uplift along the Stevens Creek fault is on the northeast side, and the rocks on both sides of the fault dip

in a northeasterly direction. The Miocene sandstones that form the greater part of the Santa Cruz Range come down to the fault-line on the west, but on the east side erosion has removed the overlying beds and exposed the Franciscan series, so that it is only at some distance away from the fault toward the east that the Miocene sandstones and gravels reappear.

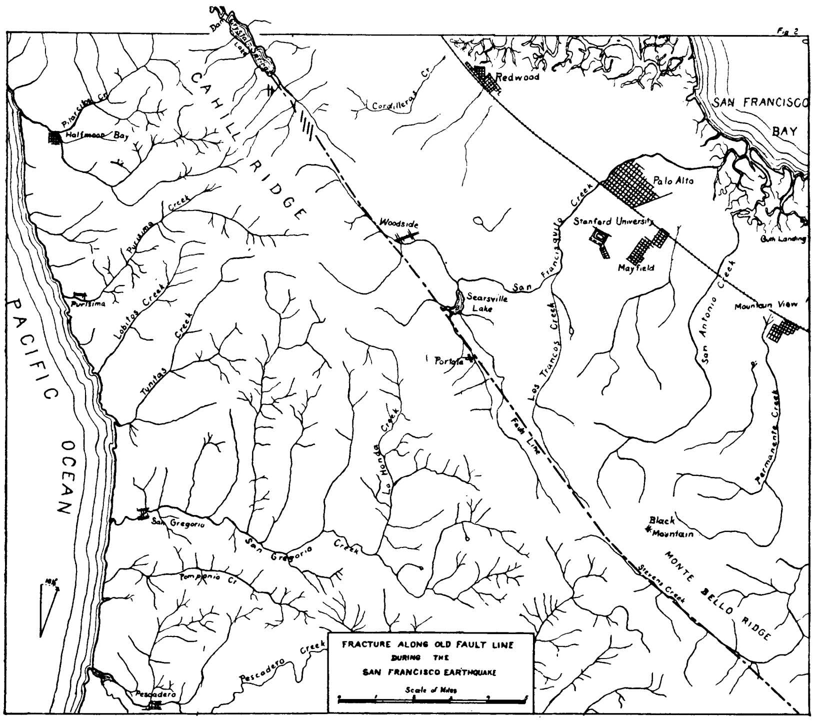


FIG. 2.

At about fifteen minutes after five o'clock on the morning of April 18, 1906, the Stevens Creek fault was suddenly refractured, and a new displacement occurred along the old fault-line, producing the earthquake that shook the adjacent region.

This new displacement is chiefly lateral, the southwest side of the fault having moved toward the northwest, or *vice versa;* and in some places this has been accompanied by a small uplift on the northeast, or a small downthrow on the southwest, or both. The

lateral displacement is well defined, as far as it has been traced, and at some points amounts to as much as 9 feet. The vertical displacement in most places is not so evident, but about a mile southeast of Portola there is an uplift of 2 feet on the northeast side, and the same amount of vertical displacement has been observed on Black Mountain.

The valleys through which the old Stevens Creek fault runs are filled with silt and gravels, so that it is impossible to get at bed-rock

FIG. 3.—Road crossing the fault-line two miles southeast of Portola. There is a vertical uplift on the northeast side of the fracture at this place.

along the fault-line, but it is probable that the rocks along this line have been so broken and crushed by past movements that they would offer little or no additional information in regard to the recent displacement.

Through the Portola Valley, and for about 3 miles northwest of Woodside, the fracture runs in a continuous and almost straight line. At a little distance it looks as though a furrow had been run down the valley with a big plow. In places the earth has been

piled up into ridges 2 or 3 feet high, and at other places fissures have been opened that measure $2\frac{1}{2}$ feet in width. Two and a half miles southeast of Portola the fissure is 3 feet across. The ground is usually cracked and broken for a distance of 10 or 15 feet on both sides of the main fracture, which in places splits up into numerous minor cracks.

Two miles southeast of Crystal Springs Lake the resistance to

FIG. 4.—Showing a fence that crossed the fault at an oblique angle. The post shown in the photograph was split and pulled apart and the wires broken.

displacement appears to have been greater, and, instead of slipping along a straight line, the ground has been broken into a belt of parallel, north-and-south, shearing cracks, running at an angle of approximately 45° with the general movement. Some of these shearing cracks are from $1\frac{1}{2}$ to 2 feet wide, and the belt of cracks extends for a quarter of a mile or more.

Black Mountain was badly shattered, and there are numerous

cracks running over it in all directions. Fences crossing the fracture are broken; those that run in a north-and-south direction have their boards bent into arches or crushed, and the ends shoved past each other, while those that cross in a northwest-and-southeast direction have been pulled apart, and wire fences have been broken by tension. Fences that cross the fracture at right angles have been broken and displaced 8 or 9 feet.

The photograph (Fig. 6) shows a line fence crossing the fault

FIG. 5.—Showing a fence that was broken and offset eight feet where it crossed the fracture.

a mile southeast of Woodside. This fence was broken and displaced over 8 feet, but had been repaired before the photograph was taken. The man at the right in the picture is holding an 8-foot transit rod, and he is standing in line with the continuation of the fence on the far side of the fracture. The crack crosses the fence just back of where he is standing.

A striking evidence of displacement is shown in the earth dam that divides the Crystal Springs Lake. This dam is about 500 feet

in length, and the road from San Mateo to Half Moon Bay runs along its crest. The accompanying sketch (Fig. 7) shows the position and direction of the cracks that were formed in the dam. The larger cracks are about 6 inches wide and are parallel with the dam. Smaller intersecting cracks were formed near the northeast end of the dam along the probable line of the fault, and the road was offset about 6 feet at this point. The fences on both sides of the

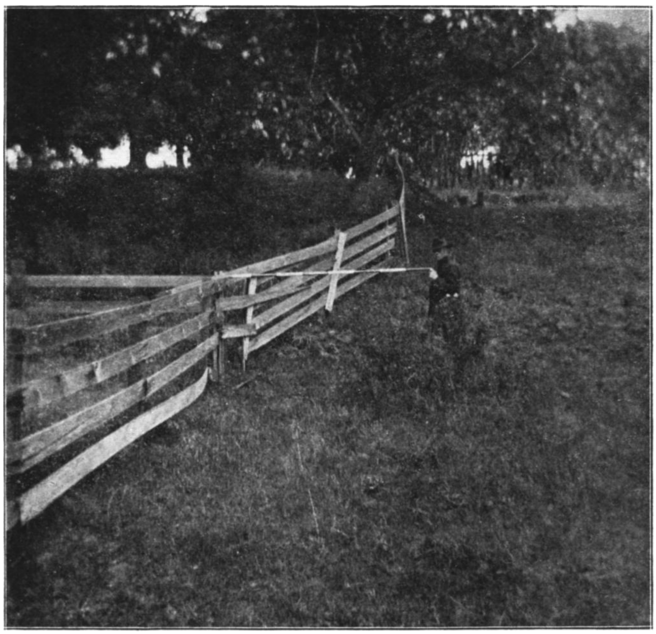
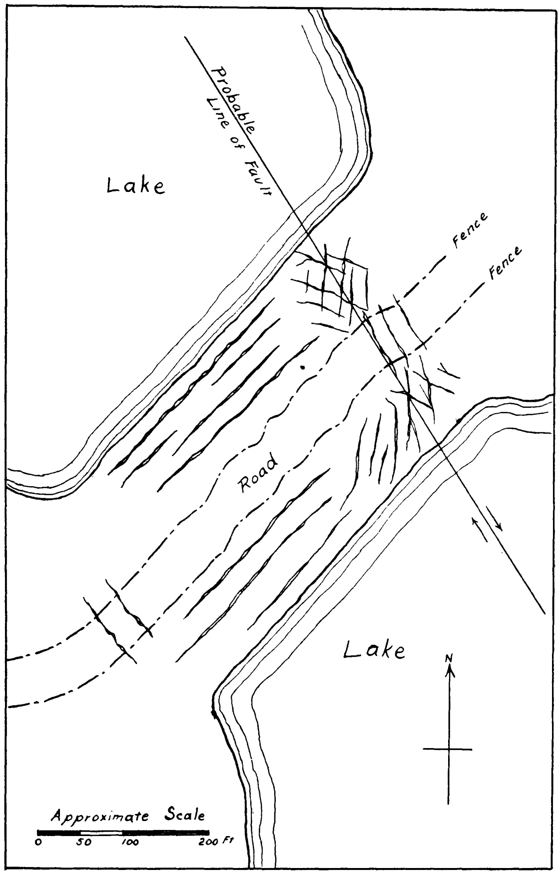


FIG. 6.—Photograph of a fence crossing the fault-line at right angles. The man is holding an eight-foot transit rod and stands in line with continuation of the fence on the far side of the fracture. The fence was repaired before the photograph was taken.

road were broken in a number of places, and the unbroken boards were bent and arched so as to give a serpentine appearance to the fences. The wires of a telephone line crossing the dam sag in great loops.

It seems probable that the total displacement is greater than the amount that may be directly measured at any place along the line of the fracture, for there is evidence of drag in the soil for a consid-

erable distance on both sides. Water-pipes at a distance of several hundred feet from the fault-line have been pulled apart, telescoped, or bent in the direction of the movement, and fences formerly straight



Dam at Crystal Springs Lake showing cracks formed by the displacement.

FIG. 7.

have been bent into a slight curve for a distance of 200 or 300 yards from the fracture.

The intensity of the shock was greatest along the line of faulting, and decreases as one goes away from this line. In comparing the

intensity of the shock at different places, the best evidence was supplied by the oak trees broken and uprooted where the intensity was greatest, by the percentage of country water-tanks thrown down, and, as the intensity decreased, by the condition of plastering in houses and the number of brick chimneys found standing.

There are many white oaks (*Quercus lobata*) growing in the valleys through this section of the country, and in a belt extending

FIG. 8.—An oak tree six feet in diameter uprooted by the earthquake three hundred yards from the fault line.

for not more than 400 or 500 yards on each side of the fracture many of these trees have been uprooted or have had large branches whipped off. Sound limbs 2 feet thick were broken off by the shock, and there are trees having a diameter of more than 6 feet that were overturned during the earthquake. About 300 yards southwest of Searsville Lake a live oak (*Quercus agrifolia*), growing within a few feet of the fracture, was split down the trunk by the violence of the movement, but is still standing.

On Cahill Ridge, 2 miles southwest of the fault-line, there are

redwoods (*Sequoia sempervirens*) that had their tops snapped off 75 or 100 feet above the ground. The intensity of the shock was much less at this point than near the line of fracture, but the redwood is brittle compared with the oak.

Frame houses, strongly built and having good foundations, stood the shock well, even when close to the fault-line, but brick and stone structures were badly damaged at distances of more than 12 miles from the fracture. Fortunately for the inhabitants, most of the houses near the fault-line were one-story frame buildings.

Most of the water-tanks that stood within 3 or 4 miles of the fracture were thrown down, but farther away the percentage of tanks that are standing gradually increases. With but few exceptions, all brick chimneys within 3 or 4 miles of the fault-line were thrown down, but at a distance of 8 or 9 miles probably more than 50 per cent. are still standing.

Within the area under discussion the earthquake seems to have consisted of two separate and distinct kinds of movement: one a violent vibration in a northwest-and-southeast direction, parallel to the fracture, and probably caused by the sudden displacement; the other a wave-motion, traveling at right angles to the fracture and generated by the rocks slipping past each other along the fault-line.

It was the first motion that snapped off branches, overturned oak trees and wrecked buildings in the immediate vicinity of the fault-line; and although this motion extended for a considerable distance, the damage it caused was limited to a belt not over a mile distant from the fracture.

The following facts appear to bear out the theory of a violent initial movement parallel to the fault-line. Most of the trees that were overturned fell toward the northwest or southeast, and the buildings that were destroyed near the line of fracture tended to move in the same direction; but frame buildings do not furnish very reliable data. Beds and furniture rolled back and forth in directions parallel to the vibration. The strongest evidence is furnished by the movement of liquids, such as milk and water. In the immediate vicinity of the fracture many places were found where the water had splashed out of reservoirs and tanks on the northwest and southeast sides, and at one place the motion had been so violent

that the water in a large wooden tank had splashed against a roof placed over it with sufficient force to drive shingles from the northwest side. In some places large water-tanks holding 3,000 or 4,000 gallons were almost emptied by the splashing.

The wave-motion was responsible for most of the damage done outside of the narrow belt along the line of fracture. Several people, who were out of doors at the time of the earthquake and several miles from the fault-line, state that the ground appeared to move like the waves of the sea. While these statements cannot be used as conclusive evidence, there are many facts that indicate a true wave-motion, having distinct crests. Water in reservoirs and tanks, standing at a distance of several miles from the fault-line, splashed out on the northeast and southwest sides. At King's Mountain House, a little over 2 miles southwest of the fracture, there were a number of milk-pans setting on shelves. All of the cream went out on the southwest side of the pans, and afterward the milk splashed back and forth, spilling out on both the southwest and northeast sides. At a barn 3 miles northeast of Woodside, heavy carriages standing with their wheels parallel to the fault-line were moved sideways a distance of 6 inches, but did not roll forward on their wheels.

At Stanford University, 4½ miles northeast of the fault-line, the sandstone buildings afford evidence of the wave-motion. Walls running northwest and southeast, when free to fall, fell by toppling over, and the stones lie on the ground in nearly the same relative positions that they occupied while standing. Walls running more nearly parallel to the direction of wave-motion were crushed, and the stones fell in irregular piles, while the walls that are still standing show 45° shearing cracks. Perhaps the best evidence of a true wave-motion is to be found in the arches. When the crest of a wave struck an arch running northeast and southwest, the arch was pulled apart, allowing the keystones to drop a short distance. There are forty-six arches running approximately northeast and southwest in which the keystones dropped, while only twelve arches running northwest and southeast had their keystones lowered, and some of the latter may be accounted for by the falling of neighboring walls. It might be well to state that there were more arches running northwest and southeast than at right angles to that direc-

tion. Most of the keystones dropped only 5 or 6 inches, but some fell out completely.

There are several strongly built, low, one-story frame houses, of the bungalow type, standing within a few hundred feet of the fault, which scarcely had their plaster cracked, excepting where chimneys fell through. Broken oak trees growing close to these houses indicate the intensity of the shock. This suggests that the

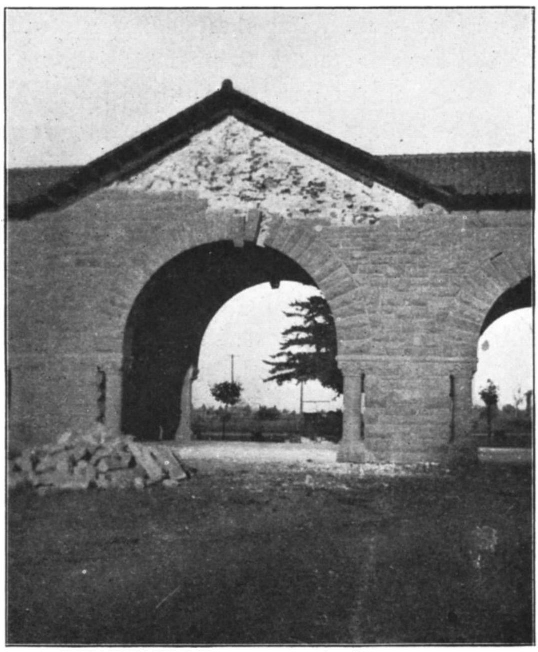


FIG. 9.—Photograph of arches at Stanford University, showing keystones lowered during the earthquake. These arches were nearly at right angles to the fault-line.

wave-motion, with its shearing action, was more damaging to walls than a back-and-forth vibration. Another interesting fact in this connection is that most two-story frame buildings at a distance of 5 or 6 miles from the fault-line did not have the plaster cracked on the second floor, although the plaster on the first floor was usually badly cracked and broken.

Brick buildings at a distance of 10 miles from the fault-line showed the effects of a wave-motion. At Guth Landing, on San

Francisco Bay, $9\frac{1}{2}$ miles northeast of the fracture, there was a large brick warehouse, with its ends parallel to the fault-line. The upper half of each end toppled over, but the side walls, although badly cracked, were left standing.

The effects of this wave-motion have not been traced more than 12 miles from the fault-line, but it probably continued with diminished intensity to a considerable distance. In other districts, having a different geological structure, the distances to which these movements could be traced would undoubtedly vary greatly. The wave-motion appears to have been more intense in the soft alluvial deposits of the valleys than in the consolidated beds that form the high ground, but there are not enough houses in the mountains of this district to furnish conclusive evidence on this point.

At Half Moon Bay the intensity of the earthquake was about the same as at Stanford University; but as one goes down the coast, and therefore away from the fault-line, the intensity decreases. At Pescadero, which is about 12 miles from the fault-line, there was scarcely any damage done, but there were no brick or stone buildings in that village.

In regard to the geological effects of the earthquake, there are a few facts of general interest that might be mentioned. Most of the landslides that occurred at this time were on the west side of the Santa Cruz Range. This is probably to be attributed to the greater rainfall on that side of the watershed. The springs and streams on both sides of the range increased in volume after the earthquake, and some creeks on the west side were nearly doubled. All of the streams were muddy for several days after the earthquake.

A marked effect was produced on the artesian belt near the head of San Francisco Bay. Wells that had previously been dry began flowing, and wells that flowed before the shock greatly increased in volume and pressure. The following is one illustration out of many that were recorded: A well near Alviso, at the head of the bay, formerly required a wind-mill to pump the water. At the time of the earthquake the casing was driven 2 feet out of the ground, wrecking the pump, and since that time the well has been flowing under a heavy pressure. In some of the lowlands small cracks were formed, out of which water issued, bringing up mud and sand.